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CONCEPTUAL DEVELOPMENT OF THE LOGISTICS CHAIN FLOW OF CONTAINER TRANSPORT WITHIN THE RHINE-ALPINE CORRIDOR

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ABSTRACT

The use of containers in the freight transport system has increased dramatically over the years. This is as a result of the interplay between macro-- and microeconomic factors and the liberalization of markets, thereby enhancing the development of international logistics services within transportation systems. The physical distribution of cargo in this system involves an integrated logistics chain process to transport the containerized goods from the production location to the consumption location.

Different logistics chain models have been used to examine the flow of the containerized goods from origin to destination, however, these models mostly capture a specific module of the chain. To address this, the paper examines the whole logistics chain by linking the interaction between the logistics cost, time, mode choice and assignment to the network, while connecting with the different innovations that could make container IWT more competitive.

In doing this, a conceptual logistics model is developed which includes the logistics cost, time, and mode choice sub-models. The two first sub-models are developed at a disaggregated level to examine the logistics decisions for the individual cargoes. The logistics decisions are derived from the minimization of transport-related costs and time and form the input of the mode choice and assignment sub-models.

Keywords: container transport, mode choice, cost, time, IWT, NOVIMOVE

1. INTRODUCTION

A large volume of port-related transport activity takes place within the containerized transport chains system. This creates a large logistics network that is used to transport cargoes from seaports to hinterland destinations. The challenge with the network is that containers are often transported inefficiently, thereby leading to higher costs, time and less competitive transport modes. Hence, the study researches how containerized cargoes can be efficiently transported from origin to destination within the logistics network. To do this, a comprehensive model is needed that would be able to model the logistics impact of transport decisions within the network, hence the cost, time and mode choice models become necessary.

This paper, therefore, presents the modelling framework of the logistics cost, time and mode choice sub-models as developed within the NOVIMOVE[1] simulation model[2]. The NOVIMOVE project aims to eliminate inefficiencies in the Inland Waterway Transportation (IWT) logistics system, thereby realising a 30% increase in inland waterways transport volumes by reducing the waiting times within the logistics system in seaports and on rivers when passing through bridges and locks. To achieve this, some innovative measures are proposed:

- Improving containers' load factors up by 20% through cargo reconstruction.
- Reducing waiting and sailing time in ports by up to 50%. This is achieved by consolidating shipments before their loading on-board inland vessels and using mobile terminals and vessel trains.
- Efficient use of the river fairway by smart navigation combining global navigation satellite system (GPS, GALILEO) with real-time river water depths data, and coordinated operation (dynamic scheduling) of bridges/locks using a decision support system.

Exploring these innovations within the project is expected to enable IWT to make better use of the inland fleet and infrastructures' capacity, and increase its reliability and competitiveness on the key Rhine-Alpine TEN-T corridor. It is with this notion that the study looks to develop the logistical cost, time and mode choice sub-models. The sub models serve two purposes within the main model. First, they are used as input in the NOVIMOVE main simulation model to establish the base case and current situation in the IWT system. Secondly, the sub models are used to estimate the impact of the NOVIMOVE innovations by comparing the base case with the IWT innovative cases, with the expected outcome that the innovations would reduce cost and lead time while increasing the modal share of container barge transport.

Based on this, this paper presents the model structure and the data sources of the logistical aspect of the NOVIMOVE project. The rest of this paper is thus structured as

[1] NOVIMOVE is the acronym for: Novel inland waterway transport concepts for moving freight effectively. A project that is funded by the European Union Horizon 2020 Program under grant agreement n° 858508.

[2] The choice of modelling method was elaborated in an earlier paper presented at SIGA 2, 2021 conference.

follows. Section 2 focuses on the methodological framework of the NOVIMOVE model. Section 3 specifies the logistics cost and time sub-model. Section 4 presents the mode choice sub-model. Section 5 discusses the data sources. Finally, section 6 concludes the paper.

2. THE METHODOLOGICAL FRAMEWORK OF THE NOVIMOVE MODEL

Different transport models are available in the literature to estimate and simulate the logistical framework of container freight transport. Examples of these models include the EXPEDITE meta-model (de Jong, Gunn, & Ben-Akiva, 2004), the micro-simulation model of shipment size and transport chain choice (de Jong & Ben-Akiva, 2007), disaggregate freight transport chain model (Jensen, et al., 2019), the TRIMODE model (Angelo, et al., 2018), the ASTRA model (Krail & Schade, 2004), the optimization model for container cargoes (Chang, Lee, Kim, & Shin, 2010), intermodal transport cost and time models (Martínez-López, Kronbak, & Jiang, 2013), the disaggregate stochastic transport model (Abate, Vierth, Karlsson, de Jong, & Baak, 2019), the econometric freight transport chain model (Abate, Vierth, Karlsson, de Jong, & Baak, 2016), logistics cost transport model (Hansen, Hovi, & Veisten, 2014), container freight optimization model (Lorenc, 2013), logistics model (de Jong & Baak, 2015), and the multimodal transport chain model (de Bok, et al., 2018) among others. Many of these models however lack the complex interaction within the IWT logistics system, such as the relationship between the cost and time calculations, selection of the transport mode based on specified parameters, assigning the flow to the network based on the selected transport modes, and assessing the impact of the different proposed innovations (As seen in *Figure 1*).

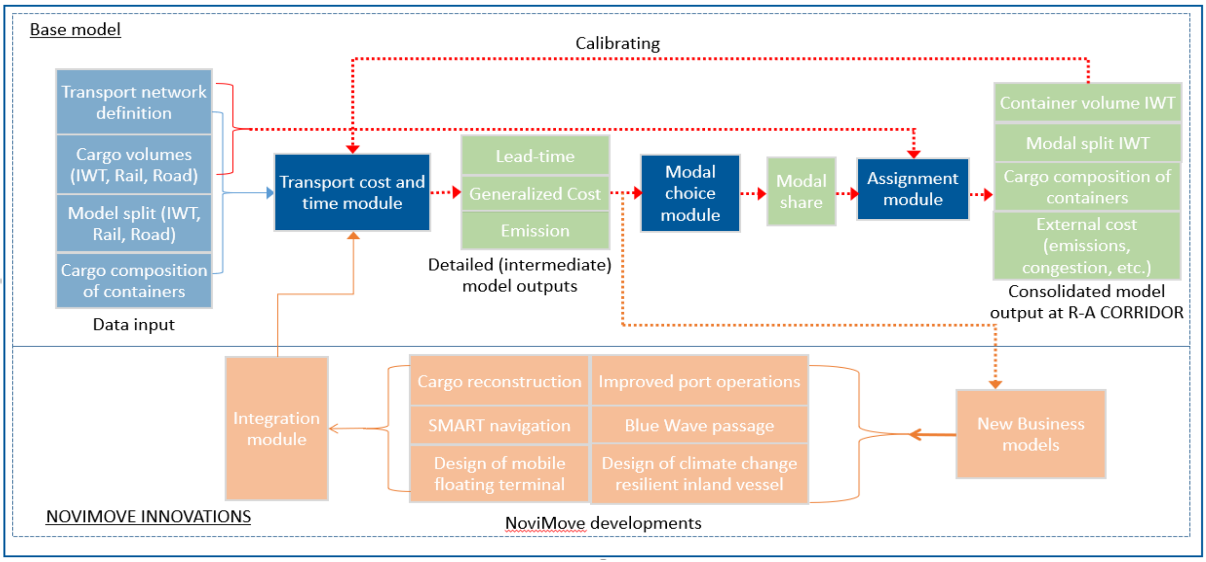

Figure 1: Interactions in the main model and between the sub-models

To implement this complex logistics structure and incorporate the innovations within the NOVIMOVE project, a discrete event simulation (DES) model is being developed. The DES is suitable when time evolvement plays an important role in the model. It is also computationally inexpensive and has various levels of details and complexity. This is suitable for the NOVIMOVE model as it will mostly depend on the level of detail and flexibility required for the simulation. Furthermore, the computational effort needed for the model to run is a determining factor, thus justifying the use of the DES model. Based on this, the requirements of the DES are specified below:

- Represents the IWT container logistics chain, including all identified actors, from seaport terminals to inland port terminals and the end destination at a distribution centre along the Rhine-Alpine corridor.
- Represents the other transport modes (road and rail), at a higher level of abstraction.
- Has a modular architecture approach.
- Calculates the impact of the NOVIMOVE main ideas and innovations on the overall performance
- Allows for gamification of the NOVIMOVE innovations (logistics, navigation, and innovative vessel concepts) for education and dissemination.

From the above, it becomes apparent that the simulation needs a large-scale network and may require some simplifications to meet the requirement for serious gaming exercise. To meet these requirements, the model will be equipped with a web interface supporting multiple users at the same time. Furthermore, specific user roles, such as barge operator, terminal operator, shipper/freight forwarder/logistics service provider, are defined. The runtime can be reduced by disabling parts of the model and focusing on a specific part of the Rhine-Alpine corridor. Finally, to ensure efficient result analysis, a high-level specific dashboard with high-level KPIs will be created. By default, large log files will be disabled. Users will be able to enable them if required. A parallel coordinates chart will be implemented to compare scenarios over multiple KPIs.
In summary, the model should be able to handle the complexity of the IWT system, where events occur in sequence and where there is high uncertainty, constraints and interactions among different actors. The simulation depicts the logistics system operations over time and is capable of representing in detail the IWT container logistics chain from seaport terminals to the distribution centres, representing at a high-level, the road and rail network, and incorporating, processing and demonstrating the impact of the different innovations on the overall performance of the IWT container logistics chain. The NOVIMOVE model will allow simulating the current IWT container logistics system on the Rhine-Alpine corridor and give detailed analyses about the impact of different innovative initiatives on the IWT container logistics.
Having highlighted the NOVIMOVE DES model, the sub models are thus further specified in this study. In doing this, the cost, time and mode choice sub-models are developed. Based on this, the mathematical representation of these models is presented in the next section.

3. LOGISITCS COST AND TIME SUB-MODEL

This section develops the logistics cost and time model for the NOVIMOVE model. The objective here is to estimate the cost and time of the paths within the network and the different modes. The cost and time model also serve as inputs to the overall DES model. Based on this, a scaled-down approach is adopted for the cost model based on van Hassel et al., (2018). This is presented below:

$$C_{gen} = C_{tran} + C_{hand} + C_{time} + C_{rel} + C_{tot,ext}$$ *Equation 1*

where;

C_{gen} = Generalized cost
C_{tran} = Transport cost
C_{hand} = Handling cost
C_{time} = Time cost
C_{rel} = Reliability cost
$C_{tot,ext}$ = Total external cost of transport.

The above cost function will further be narrowed down per transport mode and transport chain (unimodal/intermodal). In the following sub-sections, this exercise is performed consecutively for road transport, rail transport and inland navigation. After which, the external cost model is specified.

3.1. Road Transport

For road container transport, a heavy goods vehicle of total weight under 40 tonnes is used (HGV40,loading capacity 23 tonnes). The unity measurement of the container is in Twenty Feet Equivalent (hereafter TEU), thereby making HGV40 the most used for container road transport according to the European Union Statistical Pocketbook (European Commission, 2019). In line with this, the generalized cost of road transport is specified as:

$$C_{gen,road} = C_{tran,road} + C_{hand,road} + C_{time,road} + C_{rel,road} + C_{ext,road}$$ *Equation 2*

Each of these cost components is now further specified for unimodal road transport.

Transport cost: Commonly, this cost is divided into two main costs; distance-based costs and time-based costs. While the distance-based costs are expressed in EUR/vkm and include costs such as fuel price, repair and maintenance, and tires, the time-based costs meanwhile are expressed in EUR/hr and include costs such as the labour cost, depreciation, insurance and others. Based on this, the transport cost of container road transport can be specified. This is adapted from the study of van Hassel et al., (2018) and represented as:

$$C_{transport,road} = \frac{\left(C_{km,road,i} * D_{road,i.j}\right) + \left(C_{hr,road.i} * T_{road,i.j}\right) + \left(\frac{C_{hr,road.i}}{2} * T_{rest,road,i.j}\right)}{Cap_{truck} * u}$$ *Equation 3*

Where;

$C_{km,road,i}$ = Kilometre cost of road transport from origin i earlier specified (EUR/km).

$D_{road,i.j}$ = Road transport distance from origin i to destination j (km).
$C_{hr,road.i}$ = Hour cost of road transport from origin i earlier specified (EUR/hr).
$T_{road,i.j}$ = Total road transport time from origin i to destination j (hr).
$T_{rest,road,i.j}$ = Road resting time from origin i to destination j (hr). This is important for the long-distance transport on the Rhine Alpine corridor, and the cost is based on half of the hour cost.
Cap_{truck} = Load capacity of the truck (TEU).
u = Utilization rate of the truck (%). Just like the other transport modes, trucks are not always fully loaded when they operate, hence, the costs need to be spread out over the actual amount of goods that are transported.
Total road transport time is further expanded as:

$$T_{road,i.j} = T_{drive,road,i.j} + T_{cong,road,i.j} + T_{hand,road} + T_{rest,road,i.j}$$ *Equation 4*

Where;
$T_{drive,road,i.j}$ = Total road driving time from origin i to destination j [hr].
$T_{cong,road,i.j}$ = Total road congestion time from origin i to destination j [hr].
$T_{hand,road}$ = Road handling time of the cargo [hr]
Handling costs: Handling costs are based on commercial tariffs for different commodities. These tariffs differ from terminal to terminal and could range from as low as EUR 14/TEU to as high as EUR 68/TEU. The model assumes that the handling costs are independent of transport mode, shipment size, or loaded/empty containers. Hence a uniform flat rate is used across the different modes. The average rate is derived from Hekkenberg, (2013) indexed for the 2020 price level at EUR 32.5/TEU.
Time cost: For the time cost, the value of time per vehicle is multiplied by the total driving time from origin to destination. This is specified as:

$$C_{time,road} = VOT * (T_{drive,road,i.j} + T_{cong,road,i.j})$$ *Equation 5*

Where;
VOT = Value of time [EUR/hr/vehicle]
Reliability cost: The reliability cost deals with the reliability of the transport service in transporting the cargo from origin to destination. The reliability of the transport service is affected by the waiting period and the congestion level. Hence, the reliability cost is specified as:

$$C_{rel,road} = VOR * \sigma$$ *Equation 6*

Where;
VOR = Value of reliability [EUR/hr/vehicle]
σ = Standard deviation of the transport time distribution [hr]. This is based on the waiting time and congestion level.
The VOT and VOR values are based on the study of De Jong et al., (2014). In this study, VOT is the monetary change of one hour in transport time per movement, while VOR is the monetary value of a change of an hour in the transport time which is affected by the waiting/congestion time of the transport mode. The values specified in their study are the combined values from shippers and carriers that were interviewed in the study.

3.2. Rail Transport

Having described the road transport option, this section focuses on rail transport time and logistics cost. These are then combined with pre and post haulage road logistics cost and time to form the intermodal rail transport. The generalized cost for rail transport follows the same approach as with road transport and is specified as:

$$C_{rail} = C_{tran,rail} + C_{hand,rail} + C_{time,rail} + C_{rel,rail} + C_{ext,rail} \quad \textit{Equation 7}$$

Each of these components is elaborated below:

Transport cost: The transport cost of rail transport is divided into three components: fixed cost, time cost and distance cost. This is specified as given below:

$$C_{tran,rail} = \frac{C_{f,rail} + (C_{hr,rail} * T_{rail,i.j}) + (C_{km,rail} * D_{rail,i.j})}{Cap_{rail} * u} \quad \textit{Equation 8}$$

Where;

$C_{f,rail}$ = Fixed cost of rail transport (shunting cost) [train].

$C_{hr,rail}$ = Hourly cost for rail transport [hr].

$T_{rail,i.j}$ = Rail transport time from origin i to destination j [hr/day].

$C_{km,rail}$ = Kilometer cost of rail transport [km].

$D_{rail,i.j}$ = Rail transport distance from the origin i to destination j [km].

Cap_{rail} = Loading capacity of rail transport [TEU].

Regarding the load capacity of rail transport, a 500-tonne load capacity is assumed which is small compared to the maximum capacity in Europe. However, this weight is assumed as the base value due to low capacity utilization in rail transport. Hence a 500-tonne capacity is equivalent to a carrying capacity of 50 TEUs.

Total transport time for rail is determined by the driving time along the path and the various time penalties as specified below:

$$T_{rail,i.j} = T_{drive,rail} + T_{penalties,rail} \quad \textit{Equation 9}$$

Where;

T_{drive} = The driving time along the rail track [hr]. This is determined by dividing the distance by the average speed of the specified train (Electric/diesel).

$T_{penalties}$ = The various time penalties [hr]. This comprises gauge change, traction change and dwell time.

Handling cost: As earlier explained, the handling cost is estimated at EUR 32.5/TEU.

Time cost: For the time cost, the value of time per vehicle is multiplied by the total driving time from origin to destination. This is specified as:

$$C_{time,rail} = VOT * T_{drive,rail} \quad \textit{Equation 10}$$

Reliability cost: It captures the reliability of the service in transporting the cargo from origin to destination. The reliability of the transport service is affected by the waiting period of the train from origin to destination, which can be composed by dwell time and terminal waiting time. Consequently, the reliability cost is specified as:

$$C_{rel,rail} = VOR * \sigma \quad \textit{Equation 11}$$

Where;

σ = Standard deviation of the transport time distribution dependent on the waiting time, loading and unloading time [hr].

3.3. Inland Waterways Transport

The generalized cost structure for IWT is similar to the other transport modes, however, the sub-component cost structure of IWT has a different structure. Subsequently, the generalized cost is specified as:

$$C_{gen,iwt} = C_{tran,iwt} + C_{hand,iwt} + C_{time,iwt} + C_{rel,iwt} + C_{ext,iwt} \quad \text{Equation 12}$$

These cost components are further explained below:

Transport cost: The transport cost of IWT transport is divided into voyage cost and operating cost. This is specified as:

$$C_{tran,iwt} = C_{voyage} + C_{operating} \quad \text{Equation 13}$$

Where;

C_{voyage} = Voyage cost [EUR/trip]

$C_{operating}$ = Operating cost [EUR]

These two costs are further elaborated. The voyage costs are all costs associated with a specified transport journey. The cost includes; fuel cost, port dues and canal/infrastructure charges. This is specified as:

$$C_{voyage} = C_{fuel} + D_{port} + C_{infra\&canal} \quad \text{Equation 14}$$

Where;

C_{fuel} = Fuel cost per trip [EUR]

D_{port} = Port dues per trip [EUR]

$C_{infra\&canal}$ = Infrastructure and canal charges per trip [EUR]

The second element of the IWT transport cost is the operating cost. This has two main cost components; maintenance cost and fuel cost. This is expressed in as:

$$C_{operating} = C_{maintenance} + C_{crew} \quad \text{Equation 15}$$

Where;

$C_{maintenance}$ = Maintenance cost [EUR]

C_{crew} = Crew cost [EUR]

The maintenance and crew costs are further elaborated.

$$C_{maintenance} = (C_{fixed} * L * B * T) + (C_{variable} * T_{sailing} * P_{inst}) \quad \text{Equation 16}$$

Where;

C_{fixed} = Fixed maintenance cost [EUR/m^3]

L = Vessel length [m]

B = Vessel breadth [m]

T = Vessel draught [m]

$C_{variable}$ = Variable maintenance cost [EUR/kWh]

P_{inst} = Installed engine power [kW]

Crew cost: The crew cost depends on the number of crew members that are required for the vessel and their respective wages. The number of crew members is a function of the sailing regime (A1, A2 or B)[3] and the level of equipment installed on the vessel

[3] According to the Regulations for Rhine Navigation Personnel (RPN) by CCNR, A1 is the sailing regime of inland vessels (14 hours per 24 hours), A2 is the day sailing regime for IWT vessels (18 hours per 24 hours) and B sailing is a full continuous sailing operation (24hours per 24 hours). S1 and S2 are indications of equipment installed in an inland vessel. S1 means no bow thruster, in S2 indicates that there is a bow thruster.

(S1 or S2) as required by the Regulation for Rhine Navigation Personnel. Regarding the wages, van Hassel et al., (2018) assumed even wages among the crew members in a vessel. This implies that the cost of the crew members is the same for a vessel under a sailing regime and installed equipment on the vessel. Based on this, specific crew wage values (EUR/hr) are estimated for the different sailing regimes and installed equipment onboard the vessel. These values are presented in Table 1 after being adjusted to 2020 price levels.

Table 1: IWT crew cost per vessel (EUR/hr)

Vessel type	A1		A2		B	
	S1	S2	S1	S2	S1	S2
L<56m	27.64	27.64	39.31	39.31	33.92	30.05
56m<L≤86m	30.83	33.14	46.23	46.20	38.27	34.40
>86m	43	37.31	59.83	53.19	58.73	44.88
Capacity >2500t	43.32	37.65	60.62	54	59.20	45.34

Source: van Hassel et al., (2018)

Subsequently, the equation for the crew cost of a vessel is represented as:

$$C_{crew} = T_{operational} * \sum_{r=1}^{r=w} Wage_r \quad \text{Equation 17}$$

Where;

$T_{operational}$ = Operational time [hr].

w = The number of crew roles on board.

Handling cost: The handling cost follows a similar approach as with the other transport modes.

Time cost: Like the other transport modes, the time cost is determined per vessel. This is derived by multiplying the VOT by the operational time of the vessel. Subsequently, the time cost can be expressed as:

$$C_{time,iwt} = VOT * T_{operational} \quad \text{Equation 18}$$

Where;

$T_{operational}$ = Operational time [hr].

Reliability cost: The reliability cost takes a similar approach with the time cost specified above, except, in this case, the VOR is multiplied by the standard deviation of the operational time which is a function of the distribution of the port time and lock passage time. Consequently, the reliability cost is specified as:

$$C_{rel,iwt} = VOR * \sigma \quad \text{Equation 19}$$

Where;

σ = Standard deviation of operational time distribution dependent on port time and lock passage time distribution [hr].

Time model

The time structure of IWT is divided into two main components namely; operational time and operating time and handling time. This is specified as:

$$T_{iwt} = T_{operational} + T_{operating} \quad \text{Equation 20}$$

Where;

$T_{operational}$ = Operational time [hr]

$T_{operating}$ = Operating time [hr]
These two components are further elaborated on below.
Operational time: Operational time is the time used to calculate any time-related cost, such as crew cost, and maintenance cost. This time comprises the sailing time, port time and lock passage time. This is expressed as:

$$T_{operational} = T_{sailing} + T_{lock} + T_{port}$$ *Equation 21*

Where;
$T_{sailing}$ = Sailing time [hr].
T_{lock} = Lock passage time [hr].
T_{port} = Port time [hr].
These various time elements are further elaborated.
Operating time: This is the time it takes the vessel to complete the trip based on its sailing regime. This is represented as:

$$T_{operating} = \frac{T_{sailing}}{hr_{operating}} * 24$$ *Equation 22*

Where;
$hr_{operating}$ = Operating hour [hr]

3.4. External Costs

The cost models in the previous sections only focus on the out-of-pocket costs (excluding VOT and VOR) for the transport chain of either unimodal or intermodal transport of the three transport modes. However, the cost of transporting goods from the origin to the destination goes beyond just the out-of-pocket cost. While transporting the goods, some costs are borne by society that is not taken into account by the shippers.
By internalizing these costs, the effect of externalities becomes part of the decision-making process of the shippers in their decision about travel and mode of transport. Internalizing external costs can be carried out in two methods; either directly through regulations and control measures, or indirectly through market-based instruments (such as taxes, emission trading, charges). The focus here is on the second method of internalization. The method of internalization requires detailed and reliable estimates of external costs as it provides the main input parameters for the generalized costs of the different transport modes. External costs can be divided into seven main categories, which are; congestion, accident, air pollution, noise, climate change, infrastructure cost and WTT[4] cost (Korzhenevych et al., 2014; Papoutsis, Dewulf, Vanelslander, & Nathanail, 2018; van Essen et al., 2019). These categories are specified as:

$$C_{ext} = C_{acc} + C_{air} + C_{cc} + C_{noise} + C_{cong} + C_{wtt} + C_{infra}$$ *Equation 23*

where;
C_{acc} = Accident cost [EUR/tkm].

[4] WTT = Well-to-tank emissions (also known as up- and downstream processes). These are emissions due to energy production of transport activities. They can also be referred to energy production costs.

C_{air} = Air pollution cost [EUR/tkm].
C_{cc} = Climate change cost [EUR/tkm].
C_{noise} = Noise cost [EUR/tkm].
C_{cong} = Congestion cost [EUR/tkm].
C_{wtt} = Well-to-tank cost [EUR/tkm].
C_{infra} = Infrastructure cost [EUR/tkm].

In line with these categories, the external costs for the different modes can be calculated for the origin-destination regions. In doing this, the total external cost for the transport chain can be ascertained. This cost is then added to the generalized costs earlier specified to capture the societal impact of the transport activity within the transport chain. Hence, the total external cost is expressed as:

$$C_{tot,ext} = \sum_{x} (C_{ext} * D_{i,j}) \qquad \text{Equation 24}$$

Where;
$C_{tot,ext}$ = Total external cost [EUR].
x = Specific transport mode.
$C_{ext,i}$ = Average external costs of the countries in the Rhine-Alpine (RA) corridor [EUR/km].
D_i = Distance from origin to destination[km].

4. MODE CHOICE SUB-MODEL

The main goal of this sub-model is to predict the mode that will be used to transport a given shipment from its origin to its destination. There are three distinct modes of transport available along the RA corridor: IWT, rail and road. To determine the probability of choosing each mode for a given shipment, we use a variation of the Multinomial Logit (MNL). The MNL is based on the Random Utility Maximization principle applied in the context of discrete choice (McFadden, 1982; Ben-Akiva & Lerman, 1985). The utility function U_m of a mode m and the probability P_M of choosing mode M are respectively formulated as:

$$U_m = \alpha_m + \sum_{i \in I} \beta_{i,(m)} * X_{i,m} + \varepsilon_m \qquad \text{Equation 25}$$

$$P_M = \frac{e^{U_M - \varepsilon_M}}{\sum_m e^{U_m - \varepsilon_m}} \qquad \text{Equation 26}$$

Where;
I Set of attributes influencing the mode choice (e.g. cost, time, reliability, etc.).
α_m Alternative Specific Constant of mode m.
$X_{i,m}$ Value of the attribute i for mode m.
$\beta_{i,(m)}$ Coefficient expressing the importance of attribute i (can vary according to the considered mode m or not).
ε_m Error term for mode m to account for the unobserved factors influencing the outcome (follows an Extreme Value distribution).

As this method relies on decision theory, the ideal case would be having shipment data available directly from the decision-makers, e.g. shippers or forwarders. But shipment data are laborious to collect in practice: most firms keep them confidential due to their commercial nature (de Jong, 2013). Therefore, we estimate the model using aggregate data, that is OD flows (decomposed by cargo type) at the regional level. This kind of modelling makes sense in an international context as the modal share is highly dependent on the geography and commodity mix (Vassallo & Fagan, 2007). Then, OD flows between regions, especially when segmented into commodity types, are considered to be representative of the whole population (Rich, Holmblad, & Hansen, 2009).

However, an aggregated approach implies that we are unable to capture the heterogeneity in shippers' behaviour (i.e. the variation of their preferences). To remedy this issue, we propose a Logit Mixture Model. This methodology allows the coefficients β of the utility functions to be randomly distributed instead of fixed as in the MNL (McFadden & Train, 2000). The deterministic approach of the MNL assumes that the same preferences are shared by the whole population, as the coefficients do not vary. On the other hand, the Mixture Model allows for variable and random preferences among the population. By mimicking the inherent variety of decision-makers preferences, this approach should (at least partially) alleviate the lack of details induced by the use of aggregated data instead of shipment data.

Another method to capture heterogeneous preferences is the Latent Class Model. It consists of splitting the population into several classes with fixed coefficients β but different from one class to another (Greene & Hensher, 2003). We will also explore this modelling to capture different behavioural patterns according to the region type (e.g. coast/hinterland or industrial/rural) and the commodity which is being shipped.

Many attributes can influence the mode choice of a given OD pair. The cost and time, computed by the related submodel, are among the most cited decision criteria (Tavasszy, van de Kaa, & Liu, 2020). Hereby, we provide a list of other potential choice drivers that will be investigated. These first attributes are specific to each mode:

- Reliability: can be defined by the deviation from the expected duration of freight travel and is also considered among the most important criteria (Li, et al., 2020);
- Frequency: represents the number of services offered on the OD route (per day or per week);
- Accessibility: can be expressed by the number of IWT/rail terminals and highway junctions in the origin/destination regions;
- Number of transfers: should be null for road transport, but IWT and rail usually require haulage;
- Safety: can be estimated with the number of reported incidents for each mode;
- Environmental aspect: is assessed by the estimated emissions of each mode along the OD path.

Other characteristics are independent of the mode and focus on the geographical aspect:

- Shipping direction: from the hinterland to ports (export) or from ports to the hinterland (import);

- Population/Business/Industry density;
- Area typology: urban, suburban, rural, etc.

The estimation of the model will reveal whether or not each of these potential attributes significantly influences the mode choice. This procedure will use every OD pair as an observation and assume that the observed modal share is equivalent to the mode choice probability. We then compute the coefficients that maximize the likelihood to obtain the observed probabilities and retain the model with the most (statistically significant) explanatory power.

Once estimated, the mode choice submodel will be used jointly with the main NOVIMOVE simulation as depicted in Figure 2. Every time a shipment is generated in the simulation, it will go through the logistics cost and time submodel, which computes the cheapest path(s) for each mode (including pre-and end-haulage). The associated values of cost, time, reliability, etc. serve as inputs to the mode choice submodel together with the services characteristics and geographical specificities to compute the choice probability for each transport mode. The shipment is then assigned to its mode via a random drawing procedure among the computed probabilities. Finally, the assignment submodel, which is still being developed, is used to associate the shipment to a link in the network and an available service with an emphasis on the IWT. It will also keep a track of the remaining available capacity on each service or link.

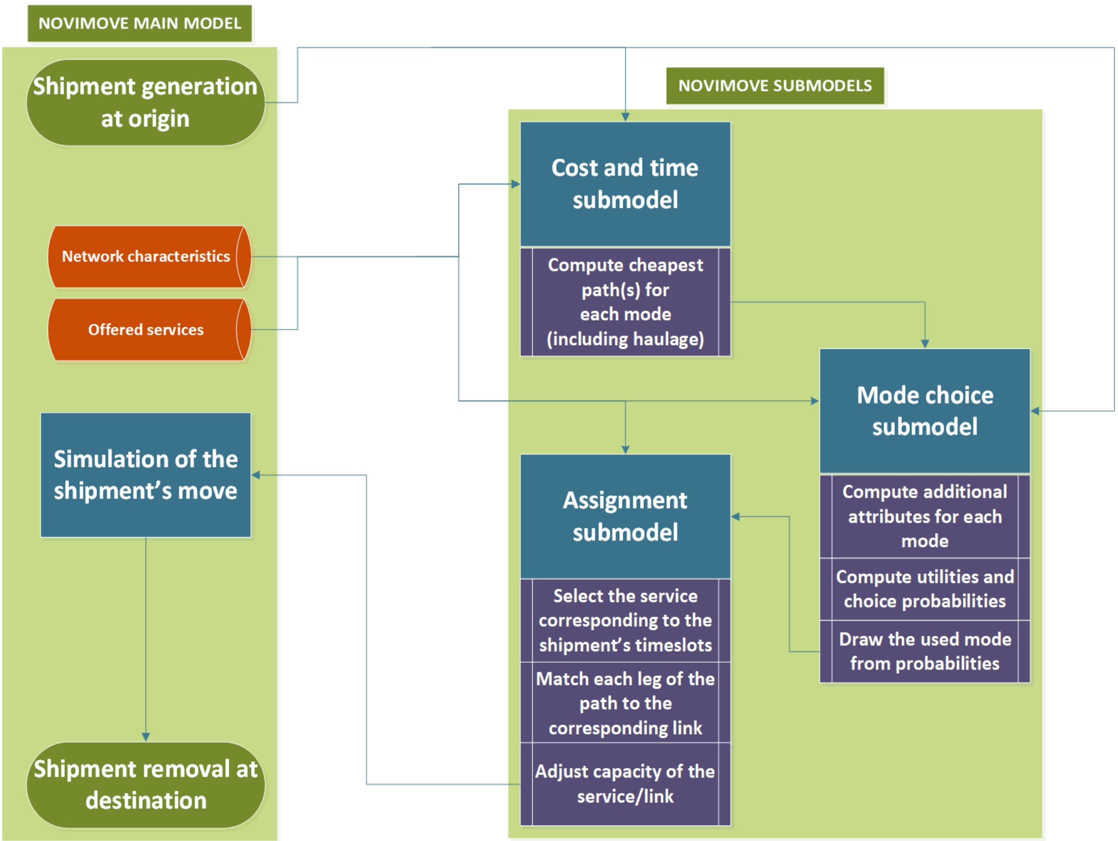

Figure 2: Flowchart of sub-models interactions with the main simulation

For the base case, we will consider that one single mode is used from a shipment's origin to its destination and that it is determined in advance. In case of disruption on a given link, we will let the delay for the shipments assigned to services that have to go through the link. For exceptional cases, such as a prolonged draught on the Rhine river, simple heuristics can be used to re-route the shipments. For example, if the draught is such that the delay reaches 5 days, then the cargo can be transshipped from barge to truck to reach its destination.
Together with the proposed NOVIMOVE innovations, the idea is to introduce a dynamic mode choice. Instead of being fixed once for all, the mode choice could be repeated along the shipment's route. In particular, if a disruption occurs, the mode choice probabilities will be recomputed with the actual network conditions and the shipment could be re-assigned to another service rather than waiting indefinitely. By proposing this dynamic mode choice, we aim to take a step toward the implementation of synchromodality.

5. DATA SOURCES

To estimate the specified cost, time and mode choice sub-models, five main datasets are used. These are BIVAS, Destatis, Eurostat, ETIS and AIS. Table 2 provides an overview of the scope of each dataset.

Table 2: Overview of the main datasets used in the NOVIMOVE project

Data source	Disaggregation level	Publishing country	Data format	Confidentiality	Restrictions
BIVAS	UNLO code/port level	NL	.csv, .xlsx	Public	N/A
Destatis	NUTS2, some port data available	DE	.xlsx, .pdf	Public	N/A
Eurostat	NUTS 2 level	EU	.csv, .xlsx	Public	N/A
ETIS	NUTS 3 level	EU	.csv, .xlsx	Public	N/A
AIS	Ship level	Worldwide	.csv, .xlsx	Public	N/A

BIVAS[5] stands for "*Binnenvaart analyse systeem*" and is developed to perform network analyses for inland navigation. BIVAS provides data of all ship movements in the Netherlands, including export, import, transit and domestic transport. The dataset has a high level of detail. Per ship journey, there is data on Ship ID, Ship type (CEMT- and RWS classification), ship characteristics (load capacity, width, length, depth), cargo volume (weight, TEU), cargo type (HS-, NSTR- and NST07 classification), origin and destination (UNLO code and NUTS3 region), date and time of departure.
Destatis[6] is the federal statistics office in Germany. It is responsible for collecting, processing, presenting and analysing statistical information concerning the topics

[5] A web application version of BIVAS is available at https://bivas.chartasoftware.com/Home.
[6] DESTATIS data is available at https://www.statistischebibliothek.de/mir/receive/DESerie_mods_00000268

economy, society and environment. Destatis releases statistics on IWW freight transport monthly in its publications and contains origin and destination matrix between german NUTS2 regions and various seaports, including Antwerp, Amsterdam, Hamburg, Rotterdam and Zeebrugge, as well as transit through Germany, and container traffic passing the borders of Emmerich, Perl/Apach and Neuburgweier/Iffezheim.

Eurostat data is used to fill part of the missing data regarding the flows. Eurostat's dataset provides information on IWW container transport flows between NUTS3 regions per NST2007 commodity type. An issue with the dataset is that the numbers for country-to-country flows differ according to the reporting country. For example, Germany reports 608,000 million TEU going from the Netherlands to Germany, while the Netherlands in contrast reports 691,000 million TEU going from the Netherlands to Germany. The difference is due to the different methods the countries use to process the data.

ETIS provides an O-D matrix for rail, road and IWT. The dataset contains transport volumes in tonnes between NUTS3 regions per NSTR commodity type for the year 2010 for IWW and rail and the year 2015 for the road. The dataset is the result of a European project called 'ETISplus' that aimed to create a common dataset of transport flows for EU transport modelling. The road dataset is useful to provide an estimation of the modal shift potential of road freight to IWW transport along the corridor.

The automatic identification system (AIS) is an automatic tracking system that uses transceivers on ships. AIS continuously transmits a vessels' position, identity, speed and course, along with other relevant information, to all other AIS equipped vessels within range. Shore stations allow port authorities, maritime safety bodies and others to collect this data as well.

6. CONCLUSION

This paper presents the conceptual logistics cost, time and mode choice submodels developed within the main NOVIMOVE model. In doing this, the modelling method (DES) was described and the parameters for the different transport modes within the submodels were specified. Furthermore, the data sources needed for the estimation of the submodels are identified. Having established the different sub-models and their interactions with the NOVIMOVE innovations, various impacts can then be expected from using the model. These are:

- An increase in container load factors.
- Reduction in the waiting and sailing time of container barges in ports and terminals.
- Efficient use of the river fairway and infrastructure.

All of which is expected to increase the modal share of container barge transport and make it more competitive. In achieving this, the developed model will be equipped with a web-interface supporting multiple users at the same time with specific user roles, such as barge operator, terminal operator, shipper/freight forwarder/logistics service provider. In line with this, the next step of this study includes the gathering and structuring of the data needed to estimate the specified models, thereby applying the model for analyzing the base case in the RA region which can be used as input in the main NOVIMOVE model.

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